

Duration magnitude estimate from local magnitude for moderate earthquakes in three provinces of Sulawesi

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Duration magnitude estimate from local magnitude for moderate earthquakes in three provinces of Sulawesi

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Abstract. The primary aim of this study is to estimate earthquake duration magnitude M_D from local magnitude M_L for a set of seismo-tectonic events in North Sulawesi, Central Sulawesi, and West Sulawesi during 2008-2015 years. The data were collected from Webdc3, comprising datasets of magnitudes in the three regions of interest. The data were firstly used to develop corresponding local magnitudes, after which these magnitudes were analyzed to parameterize duration magnitude. Using a simple parametric equation (adopted from relevant work) directly linked M_D to M_L , $M_D = 1.05 M_L - 0.17 + c$ where c represented a correction factor, we found that the equation is applicable to moderate events considered with no significant difference in the calculated values whether or not c was used. For completeness, we compared the M_D values in the three provinces with M_W scales provided by the Global CMT catalogue as the reference. The results show that the obtained values of M_D are in good agreement with the magnitude reference of M_W within ± 0.2 units in magnitude. The results suggest that empirical relations between M_D and M_L used here are appropriate for rapid and accurate magnitude determination to improve seismic hazard assessment in the three provinces.

1. Introduction

Hazard mitigation study associated with earthquakes involves a method of earthquake early warning that comprises conceptual methods and possible applications [1]. In this context, a physical quantity of importance differentiating a particular earthquake source from another is earthquake magnitude [2]. For regions that are vulnerable to seismo-tectonic hazards, such as Sulawesi Island as one of islands in the eastern Indonesian provinces, the problem of hypocenter relocation and magnitude determination was claimed vital due to tsunami potential in the regions [3]. In response to this, [4, 5] used broadband seismograms recorded by a network of local stations in Sulawesi to estimate accurate local magnitudes generated from data of P -wave dominant periods. Another important parameter related to the source is signal duration formerly introduced by [6] as a measure of a tsunami discriminant. This duration was then used by [7] to evaluate Indonesian tsunami early warning system.

The primary purpose of this study is to estimate earthquake duration size from possible quantities, including signal duration and local magnitude recorded by local seismic station networks surrounding the epicenter. The signal duration generated by *Joko Tingkir*, a software validated in [8] for use, can be used to determine duration magnitude but many seismologists [9, 10, 11] were particularly in favor of a direct scaling relation of duration magnitude and local magnitude, with which we are here concern. Thus, magnitude estimate using this scaling is crucial for earthquake early warning in Indonesia.

2. Methods

A total of 72 moderate earthquakes in majority recorded by a network of local seismic stations in North Sulawesi with all hypocenters at sea depth and magnitudes in the range of $4.0 \leq M \leq 7.5$ during 2010-2015 previously examined by [4], along with other 50 local occurrences in Central Sulawesi and 37 local earthquakes in West Sulawesi previously explored by [5] having the same magnitude range as that occurred in North Sulawesi but recorded during 2008-2015 with hypocenters distributed below the seafloor and land at depth, were used in this study. Geographical positions of the three provinces are respectively $0.25^\circ - 5.57^\circ$ N and $123.12^\circ - 127.17^\circ$ E for North Sulawesi, 2.37° N – 3.80° S and $119.37^\circ - 124.37^\circ$ E for Central Sulawesi, $0.20^\circ - 3.63^\circ$ S and $118.72^\circ - 124.90^\circ$ E for West Sulawesi. In all cases, most of the events considered are shallow sources of less than or equal to 100 km deep with moderate magnitudes (see figure 1).

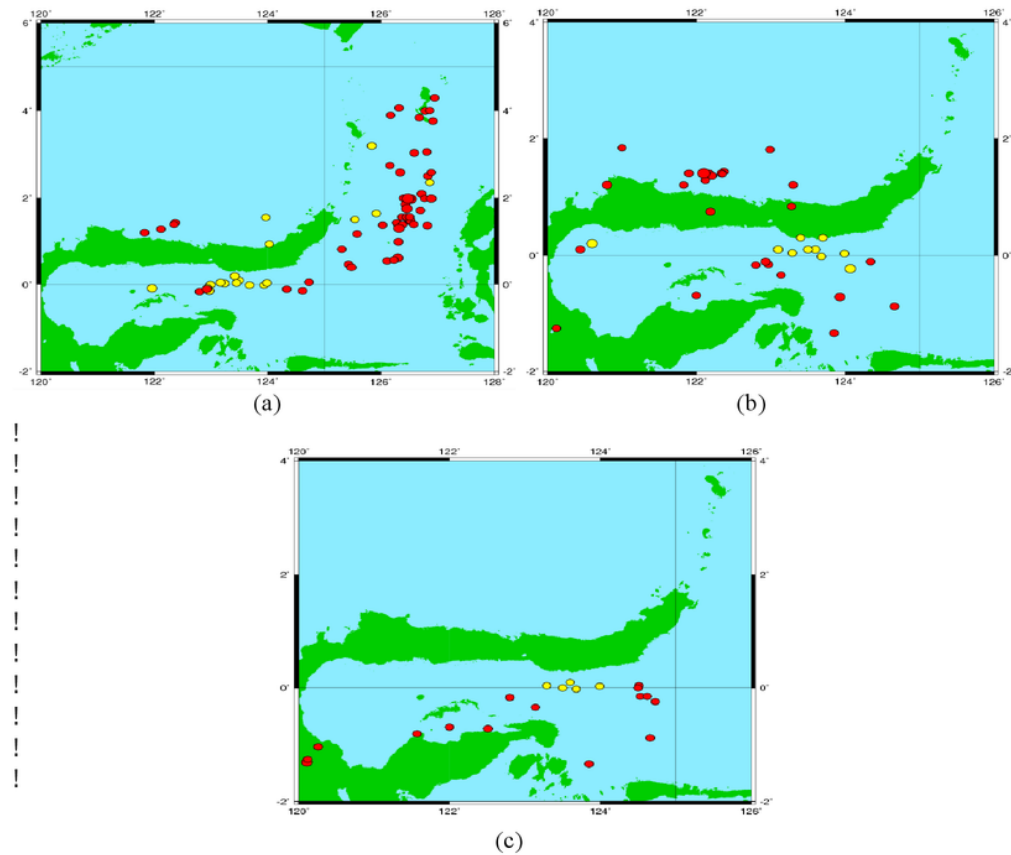


Figure 1. Distribution of moderate earthquakes recorded by local stations in North Sulawesi in (a), Central Sulawesi in (b), and West Sulawesi in (c). Note that red-circles denote events with relatively shallow sources of ≤ 100 km and yellow-circles represent those with hypocenters located at a depth of 100-300 km. The size of a circle, either red or yellow, relates to earthquake magnitude measured, where the dominant size shown reflects moderate scales in magnitude ($4.0 \leq M \leq 6.0$).

2.1. Data collection

All considered events that occurred in the three regions of interest and their corresponding datasets of earthquake magnitudes were freely accessible as high-frequency broadband seismogram data from <http://eida.gfz-potsdam.de/webdc3/>. Their associated magnitudes for each region were then obtained

from the Global CMT catalogue at <http://www.globalcmt.org/>, where the magnitudes were considered as reference and were symbolized as M_W in this study. Local magnitudes M_L for all events used here were taken from [4] for North Sulawesi and from [5] for both Central Sulawesi and West Sulawesi.

2.2. Data analysis

The primary method used in this study was to develop a line of best fit with a correction, if necessary, using paired datasets of earthquake magnitudes given for each region of interest. Initially, we adopted techniques in [9, 10] using signal duration data (not provided here) to generate duration magnitude M_D but found unclear relation between the resulting magnitude M_D with respect to magnitude reference M_W by the Global CMT catalogue. This included a small correlation coefficient for the regression line generated, leading to a failure in duration magnitude determination. Considering this failure, we used a different scale, similar to the one discussed in [11], where M_D was directly linked to local magnitude M_L from both [4] and [5]. Using this method, we estimated duration magnitude for the three provinces with an additional factor c to take the effects of local sites and instruments into account and wrote it as $M_D = 1.05 M_L - 0.17 + c$, adopted from [11]. During examination of this mathematical expression for the three provinces, we found c to be negligible and hence we used $M_D = 1.05 M_L - 0.17$ only to derive duration magnitude estimates M_D from local magnitudes M_L for this work.

3. Results and discussions

The results of earthquake duration magnitude estimate for all events examined in the present study are detailed below and the corresponding discussions follow. This includes statistical analysis of the data obtained in each region. For reasons associated with epicentral distances between the epicenter and local stations positioned nearby the source in the three provinces, we strongly argue that the methods developed by [4, 5] relying on the dominant periods of P -waves for local magnitude estimates are not appropriate for this case. Signal, or more precisely earthquake rupture, duration is likely to be a good parameter to consider for teleseismic earthquakes rather than local events, as is the case here. Hence, we do not use techniques as in [4, 5] with rupture duration data for magnitude determination.

We then perform 'trial and error' to search for a possible scaling relation of duration magnitude and rupture duration, as also suggested by [9]. Using a modified scale of that proposed in [9] with no and with station corrections, we find duration magnitudes for the three provinces are mostly comparable with the references but are not well constrained for this case. We here argue from regression analysis that the signal duration data may provide a single linear relation to the duration magnitude but with small values of a correlation coefficient for the best fit in each region that lead to small confidence. This is perhaps an important step for redefinition of what is necessary for magnitude determination, whether or not signal duration is needed.

After failures in using rupture duration data for magnitude determination, we finally make progress by adopting the method discussed in [11]. This method claims in favor for scaling relations of moment magnitude M_W , duration magnitude M_D and local magnitude M_L for moderate events in North India with sizes in the range of 3.0 – 5.5. Having examined the scaling relations between the three measures of magnitudes and the differences in geological settings between regions of North India and Sulawesi that may be present, we propose $M_D = 1.05 M_L - 0.17 + c$ where c is largely influenced by local effects. We examine carefully for all events and find that c plays no important role as it is on the order of 10^{-3} , hence negligible, meaning that the c factor in the proposed scaling is insensitive to local stations at relatively short distances. This argument is supported by [10, 11], claiming that no significant change in the best-fit lines of linear regression is present when the correction factor is further added. We then use $M_D = 1.05 M_L - 0.17$ to estimate duration magnitudes from local magnitudes for moderate events examined in the current study.

We may also argue here that values of M_D obtained from the scaling relation, $M_D = 1.05 M_L - 0.17$, are adequately accurate and rapid for magnitude determination. This is sensible as local magnitudes M_L are accurately determined with respect to the magnitude references M_W , as suggested by [4, 5]. Thus, we may expect linear regression of M_D versus M_W for the datasets given with a relatively large value of R^2 for the best fits obtained. Shown below in figure 2, plots of M_D versus M_W for the provinces of North Sulawesi, Central Sulawesi, and West Sulawesi.

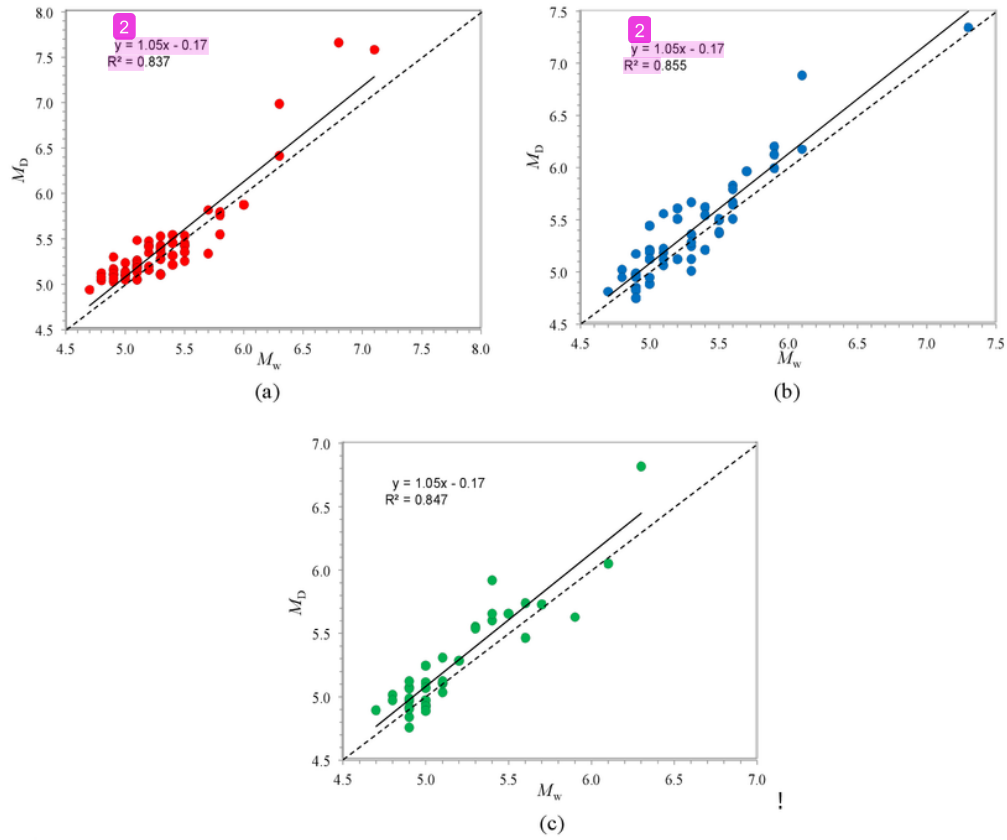


Figure 2. Plots of duration magnitudes M_D obtained from the scaling relation of $M_D = 1.05 M_L - 0.17$, where M_L is the local magnitudes derived from previous work [4, 5] with respect to the references measured in M_W by the Global CMT catalogue for North Sulawesi in reds (a), Central Sulawesi in blues (b) and West Sulawesi in greens (c). Note that black-solid lines are lines of linear regression for each province (generated by datasets of M_D and M_W) and black-dotted lines denote ‘virtual-events’ that would have equal magnitudes measured in both M_D and M_W .

It is seen from figure 2 that at least two features of primary importance can be extracted, regarding the distribution of duration magnitudes M_D with respect to the references M_W . For the three provinces, the majority of the data, in particular events with $4.0 \leq M \leq 6.0$, collapses into a likely single equation of the best fit generated, $M_D = 1.05 M_L - 0.17$ with the large correlation coefficient, $R^2 > 0.83$. Further, all the duration magnitude estimates M_D are insignificantly different from the reference magnitudes M_W as these estimates are consistent with the references with the calculated standard deviations of only 0.20 for North Sulawesi, 0.19 for central Sulawesi, and 0.17 for West Sulawesi (or in general of up to 0.2 to one decimal place). The same value of standard deviation was also reported by [4, 5] for local magnitude determination based on the dominant period of P -waves in the three provinces.

However, some points representing events with relatively large sizes of $M > 6.0$ are overestimated by this scaling, relatively compared with the references. This finding suggests that the scaling relation between duration magnitude and local magnitude adopted from [11] and used here seems appropriate for moderate events only with magnitudes of up to 6.0, after which magnitude estimates are generally larger than expected (compared with the reference provided by the Global CMT catalogue). This is not

surprising as the local magnitude scale fits only to the moment magnitude of up to 6.5 in size [12]. With increasing sizes, the local magnitude estimates are systematically deviated from the references.

4. Conclusions

This study aims to estimate duration magnitude M_D from local magnitude M_L for moderate events in North Sulawesi, Central Sulawesi, and West Sulawesi during 2008-2015. The local magnitudes were firstly analyzed to parameterize magnitudes based on rupture duration but providing unclear relations. Following the method developed by [11], we use a simple equation which directly connects M_D to M_L , that is, $M_D = 1.05 M_L - 0.17$ to estimate the duration magnitudes from their corresponding local sizes for all moderate events in the regions of interest. We find small differences in corrections originated from site and instrument effects for the three provinces and therefore the corrections are unimportant. The results for M_D scale are compared with magnitude reference M_W from the Global CMT catalogue. Direct comparison between these values shows that M_D estimates are consistent with those measured in M_W within ± 0.2 units in size. This suggests that the relation of M_D and M_L used here is reliable for rapid and accurate magnitude determination to evaluate seismic hazards in the three provinces.

Acknowledgments

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